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Virtual restoration of the sound of the Hispanic Rite

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Summary
The virtual acoustic reality techniques are powerful tools for the recovery of acoustical heritage of historic buildings. Through the acoustic modeling and auralization techniques it´s possible to reconstruct the sound of disappeared buildings or the ones with significant modifications over the years, knowing the original geometry and the acoustic characteristics of their surfaces.
This paper shows the results of a research project whose goal is the virtual recovery of the sound of the Hispanic Rite, the rite celebrated by Christians of the Iberian Peninsula before the imposition of the Roman Rite in the mid-eleventh century. For this purpose, acoustic models of a series of Pre-Romanesque churches were made. These acoustic models represent the churches in their original state, following the reconstruction hypothesis proposed by leading researchers in medieval liturgical archeology. Multichannel anechoic recordings of several pieces of the music of the Hispanic Rite have been carried out using a spherical array composed of 31 microphones. Finally, static and dynamic auralizations have been developed, involving the different liturgical configurations which were usual in this rite.

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1. Introduction

One of the most interesting applications of the Acoustic Virtual Reality technologies is the possibility to recover the cultural heritage of the sound of the historical sites that have been lost or whose characteristics have been modified through time. In recent years several research projects there have been carried out with this goal, among them, the ERATO Project [1] aimed at the identification, evaluation and revival of the acoustical heritage of ancient Theatres and Odea, and CAHRISMA Project [2] which deals with audio-visual reconstruction of Sinan's Mosques and Byzantine Churches.
In this work, Acoustic Virtual Reality technologies are used to try to reconstruct virtually the sound produced in the liturgical activities of the Hispanic Rite. It is a lost cultural heritage, both from the point of view of the sound signals that were used since the majority of the melodies that conformed the rite have been lost, and from the point of view of the spaces in which this liturgy was celebrated, because the churches preserved from that era have changed over the centuries altering its acoustic conditions respect to which they were in the period in which this liturgy was in effect.

2. The Hispanic Rite

The Hispanic Rite (also known as Visigothic or Mozarabic rite) is one of the most interesting cultural manifestations of the Middle Ages. This is the name given to the liturgy celebrated by Christians of the Iberian Peninsula prior to the introduction of the Roman cult in the mid-eleventh century.
The Hispanic rite was developed in the early centuries of Christianity and became widespread after the political and religious unification fostered by the Visigothic kings. The high point in their consolidation and dissemination was the seventh century, when the rite was celebrated throughout the Iberian Peninsula.
During the reconquest of the territory occupied by the Arabs, a gradual process of replacing the Hispanic Rite by the rite used in Rome and the

Frankish kingdom (called Roman Rite) was initiated. This process culminated in the abolition of the Hispanic Rite in 1080.

When King Alfonso VI reconquered Toledo, the inhabitants of the city (known as *Mozarabs*) were granted with a number of privileges in recognition of their resistance and cooperation in the fight against the Arabs. Among the conferred privileges, the King granted them continuing holding their ancient liturgy in the six parishes which existed at that moment. Thus, the Hispanic rite survived, though not without difficulties, in the following centuries, transmitted orally from generation to generation

2.1. The music of the Hispanic Rite

As in other early Christian liturgies, music was the core of the Hispanic Rite. This music, known as "Mozarabic Chant", is considered without a doubt one of the richest musical repertoires of the Middle Ages.

The liturgy of the Hispanic Rite has been documented in a large number of manuscripts. These manuscripts also contained the music that accompanied the text, but written in a kind of primitive notation that does not decrypt the sounds pitch, which makes it impossible to be interpreted. The oral transmission of the repertoire through centuries caused the melodies transcribed using a more precise notation at the end of the 15th century differ significantly from the ancient ones.

To date, musicological research has only been able to recover the music of about twenty pieces of the original repertoire [3].

2.2. The spaces of the Hispanic Rite

The spaces in which the Hispanic Rite was developed and practiced are the pre-Romanesque churches of the Iberian Peninsula. This designation includes a large and heterogeneous group of buildings which have lost some of the most significant constructions and many others have had substantial modifications throughout the centuries.

These are, in general, churches of small dimensions compared with those of later times. Their shapes and construction techniques are characterized for not following a homogeneous pattern, both in the floor plan shape (basilica, cross-shaped or mixing both) and in the type of roof (there are vaulted roofs with different types of vaulting as well as wooden covers following the Roman tradition).

3. Room modeling and auralization

To carry out this project, acoustic models of a representative group of the pre-Romanesque churches in the Iberian Peninsula have been made, according to the historical reconstruction hypothesis that have been proposed in the most recent archaeological investigations. Anechoic recordings of several pieces of original music of the Hispanic Rite have been performed. Finally, static and dynamic auralizations were produced corresponding to different liturgical configurations which were common in this rite.

3.1. Selected Churches

To select the sample of buildings to study, efforts have been made to ensure that the selected churches were representative of the expected range of acoustic behaviors in this type of buildings. The sample should contain buildings with differences in the parameters that have the greatest influence on their acoustic behavior: the enclosure volume, the floor plan shape and the type of roof. An additional requirement is the condition of the churches, which should be good enough to perform acoustic measurements to validate the virtual models. It has also been required to have archaeological documentation enough to reconstruct the buildings in their primitive state.

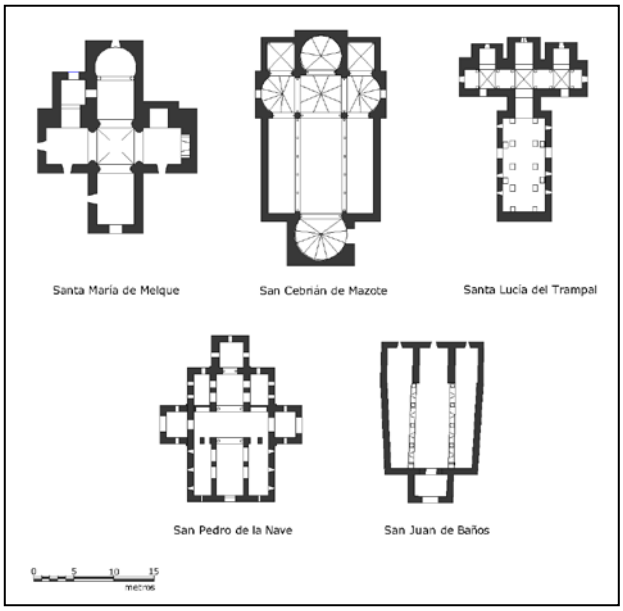

Figure 1. Floor plans of selected churches in their present state.

Table I. Geometric and constructive parameters of the selected churches.

Church	*Date of construction*	*Vol. m^3*	*Floor plan shape*	*Roof type*	
				Present	*Primitive*
San Juan de Baños	7^{th} century	928	Basilica	Wooden	Wooden
Santa Lucía del Trampal	9^{th} century	745	Basilica	Wooden	Vaulted
San Pedro de la Nave	7^{th}-9^{th} century	780	Mixed	Mixed	Vaulted
Santa María de Melque	10^{th} century	1220	Cruciform	Vaulted	Vaulted
San Cebrián de Mazote	10^{th} century	2700	Basilica	Wooden	Wooden

Based on these premises, five pre-Romanesque churches have been selected: **San Juan de Baños**, as small basilica, **San Cebrián de Mazote** as large basilica, **Santa María de Melque** as an example of a cruciform church, **San Pedro de la Nave** representing the churches with mixed floor plan and **Santa Lucía del Trampal** due to its structural uniqueness. Figure 1 shows the floor plans of the churches in their current state and Table I presents the most important geometric and constructive parameters as regards to their acoustic behavior, both in its present and primitive state.

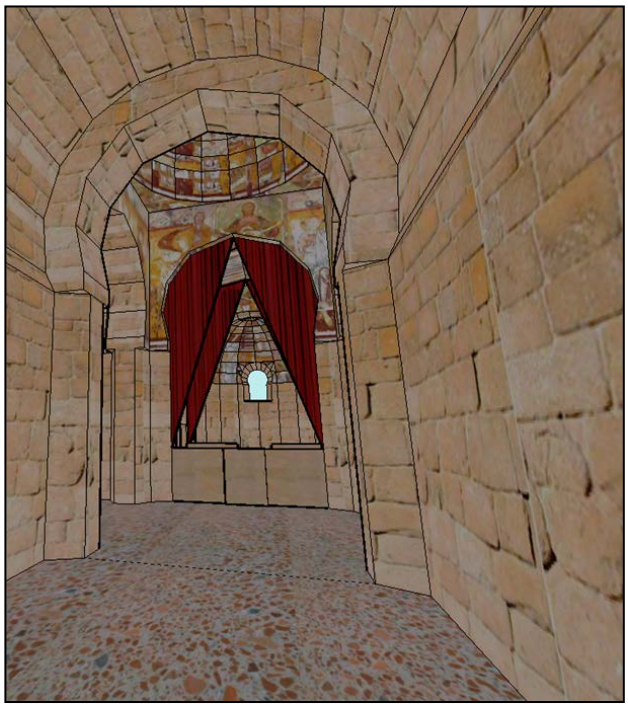

Figure 2. Interior view of one of the churches made with SketchUp 8.

3.2. Room modeling

The process of creating digital acoustic models of the churches has been divided into two phases. In the first phase acoustic models of the churches in its current state have been created. These models have been validated with the data obtained from *in situ* acoustic measurements [4]. From the validated models of churches in its current state, in the second phase, changes in the acoustic models have been performed in order to represent the primitive state of the churches, according to the reconstruction hypotheses found in the consulted archaeological literature.

The simulation has been based on the room acoustic simulation software RAVEN [5][6], developed by the Institute of Technical Acoustics, RWTH Aachen. This software combines a deterministic Image Source method for the calculation of early reflections with a stochastic Ray-Tracing algorithm for the late reverberation, including wave effects of sound scattering, sound transmission and sound diffraction.

Geometric models of the churches were generated with SketchUp 8, which is used as GUI in RAVEN through a plug-in that manages the selection and positioning of sound sources and receivers, and automatically sends all acoustically relevant data to the simulation module, including room polygons, assigned wall materials, source and receiver characteristics and auralization configuration.

The RAVEN framework provides a realistic sound field rendering with a very low latency time, which allows that freely movable sound sources and receivers are supported at runtime.

3.3. Anechoic recordings

To perform the auralizations of the sound of the Hispanic Rite it's necessary to have anechoic

Table II. Auralization parameters.

Environmental	Air temperature	20 °C
	Air humidity	50 %
	Air pressure	101325 Pa
Sound source	Source directivity resolution	10° x 10° full sphere
	Image sources order	2
	Number particles (Ray Tracing)	10 octaves x 100,000 rays
Receiver	Time resolution (Ray Tracing)	10 ms
	Radius detection sphere (Ray Tracing)	0.4 m
HRTF	HRTF database	ITA Aachen Dummy Head
	HRTF resolution	3° x 3° full sphere
Walkthrough Auralization	Convolution block size	512 Samples @ 44.1 kHz
	Image sources update	Every block
	Ray Tracing update	Every 1 m translation

recordings of Mozarabic Chant. For this purpose, anechoic recordings were made for a number of musical pieces representative of the Mozarabic Chant repertoire [7]. In total eight musical pieces, each one interpreted by six different singers, have been recorded. The recording was made separately for each one of the singers.

A simultaneous recording of the sound signal with two types of microphone systems has been carried out: a main system consisting of a pair of high quality and low noise microphones, to get the master signal used for auralizations, and a spherical array of 31 microphones intended to measure the voice directivity of the singers in real-time.

The interpolation of the data obtained by the spherical array onto a higher spatial resolution has been done by a Spherical Harmonic Transformation (SHT) of the recorded data. The results have been converted to OpenDaff format to be used as data directivity of sound sources in the acoustic simulations.

The musical pieces recorded have been performed by members of the musical group *Schola Antiqua*, highly reputed in the interpretation of medieval liturgical music, especially in the repertory of the Mozarabic Chant.

3.4. Auralizations

Two types of auralizations, static and dynamic, have been carried out. In the static auralizations sound sources and receivers are located at fixed positions. According to historical documents describing the rite [8], the sound source that simulates the officiant has been located at the main apse. The sound sources that simulate the other celebrants were distributed into two groups located in front of the apse, emulating the two choirs that alternate in singing in the antiphonal parts. For one of the musical pieces, in addition to those representing celebrants, sound sources have been distributed across the nave in order to simulate the faithful in the public liturgy. In all cases, the auralizations have been performed at several receptors positions distributed across the nave and the choir.

In dynamic auralizations, movements of the sound sources and receivers have been simulated. The most interesting aspect of this type of auralization is to restore the sound perceived in ritual processions, which were common in the Hispanic liturgy.

Dynamic auralizations were not be performed in real time, but the displacement of each one of the moving elements has been previously established, then, the binaural impulse responses and auralizations for all points of the trajectory have been calculated.

Figure 3 shows the order of movement of sound sources in the dynamic simulation of a ritual procession in the church of Santa María de Melque.

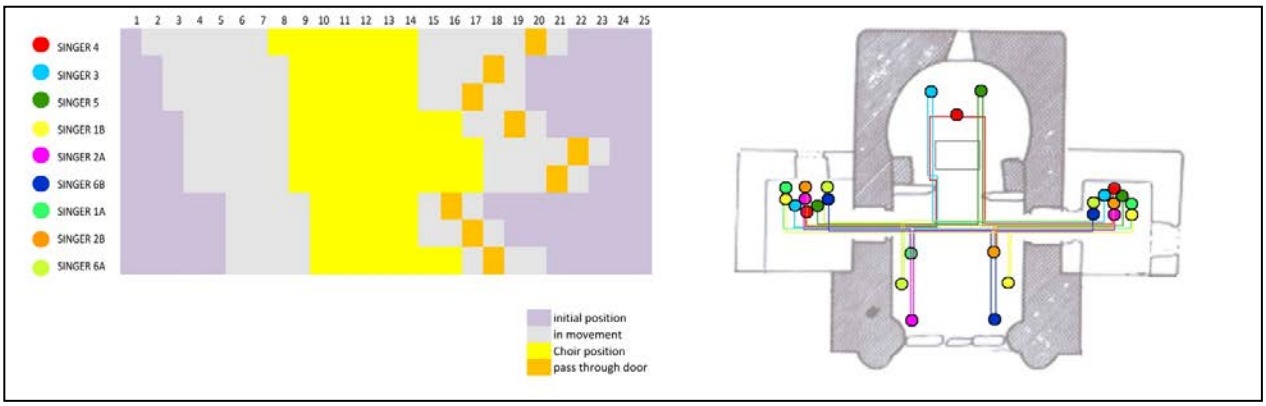

Figure 3. Example of sound sources movement in a dynamic auralization.

4. Conclusions

Using virtual acoustic reality technologies, the acoustical heritage of the sound of the Hispanic Rite has been recovered in a group of pre-Romanesque churches. To do this, digital acoustic models of churches representing the state they had in the Middle Ages have been produced. Anechoic recordings were performed on a representative sample of the tunes that have been recovered from the original Mozarabic Chant repertoire. Finally, static and dynamic auralizations have been carried out representing different liturgical configurations which were usual in this rite.

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